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THE ROLE OF HYDRATION ON PERIPHERAL RESPONSE TO COLD

D. E. Roberts, Ph.D. and J. J. Berberich, M.D., Ph.D.

U.S. Army Research Institute of Environmental Medicine
Natick, MA 01760

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Address Reprints Requests to:

Dr. Donald E. Roberts
USARIEM
Cold Injury Branch/Cold Research Division
Natick, MA 01760

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These subjects experienced a cold test prior to and after dehydration and after rehydration. The fingers, but not the back of the hand, of the dehydration group were significantly colder (P<0.5) following dehydration. A group of 10 control subjects tested under identical conditions, but hydrated at all times, showed no changes.

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ABSTRACT

Ten men were dehydrated by restriction of fluid intake and by exercise over 2-1/2 days (weight loss: 4.6%). Body weight returned to −1.6% within 10 hours after rehydration, suggesting the weight loss was fluid loss. Measures of blood and urine constituents also were indicative of dehydration.

These subjects experienced a cold test prior to and after dehydration and after rehydration. The fingers, but not the back of the hand, of the dehydration group were significantly colder ($P<0.5$) following dehydration. A group of 10 control subjects tested under identical conditions, but hydrated at all times, showed no changes.

INTRODUCTION

The physiological response to peripheral cooling may depend on environmental factors, such as prior cold exposure (1, 2, 3), physical training (4, 5) and hydration state (6, 7). Possible genetic and racial differences have also been reported (8, 9, 10, 11).

Several studies (12, 13, 14, 15) have shown that hypohydration is a problem in cold climates. Men exposed to arctic survival conditions in tents with ad libitum water (no food) lost 8% of their body weight in 5 days. Based on the electrolyte loss, 62% of this loss was attributed to fluid loss (13). Canadian military operations in cold climates have indicated that dehydration was a major contributing cause of casualties and

loss of effectiveness of troops. It was found that troops exhibited a six to ten percent body water deficiency when diagnosed as dehydrated and often required evacuation (12). In one Canadian military exercise, lasting 5 days, a fluid loss of 3% was estimated (14). U.S. military exercises in Alaska have reported a casualty rate of 1.8% which was attributed to dehydration by the examining physician 15).

Dehydration may also alter the peripheral response to cooling. It is known that peripheral heat transfer rates in a warm environment are affected by the state of hydration, in resting or working subjects (16, 17, 18). These studies have shown that hypohydration caused an increase in equilibrium rectal temperature of 0.1^{0}C for each 1% reduction in body weight. This increase in core temperature was due to a reduction in peripheral blood flow and inadequate evaporation. A similar reduction in blood flow in a cold environment due to hypohydration could lead to an increase in the rate of peripheral cooling in hands which are dependent on blood flow for their warmth. This study was performed to explore the questions concerning the role of hydration on the peripheral response to cold exposure.

METHODS

Twenty-four male volunteers having a mean weight of 75 $\pm$ 2 kg, mean height of 69 $\pm$ 0.5 inches, and a mean age of 21.7 $\pm$ 0.3 years were used for this study. The subjects were divided into 2 groups; control and dehydrated, with each group having a similar

body weight distribution. During the test, all subjects were housed in an isolation area and fed packaged frozen foods. The menu differed during the week, but was matched for both groups. Exact caloric balance was not calculated, but food intake exceeded 2500 kcal per day.

All subjects experienced the standard hand cooling test at least one week prior to their test week to minimize novelty effects. During the test, all subjects experienced the cold test on 3 different days: Monday (before dehydration); Thursday (after dehydration); and Friday (after rehydration). Each subject was tested at the same time of day for each cold exposure.

Dehydration. The primary measure of dehydration was body weight loss. Each subject was weighed each morning immediately upon arising to obtain a systematic weight. Weights were taken clad only in shorts to the nearest 0.01 kg using a calibrated balance.

As indirect corroborators of dehydration, measures of various blood and urine constituents were made. A blood sample was drawn each morning in the supine position before arising by venipuncture of the antecubital vein. Urine samples were collected as 12 hour samples starting Monday at 0630 and continuing for the entire week. Blood samples were analyzed for hematocrit, hemoglobin, serum osmolatity, sodium, potassium and chloride by standard clinical methods. Volumes of the 12 hour urine samples were measured and the urine analyzed for specific gravity, sodium, potassium and chloride.

Starting at 1400 Monday, the dehydration group subjects were dehydrated by voluntary restriction of fluid intake and by mild exercise. Apart from the fluid contained in their meals, the dehydration subjects received only one liter of fluid over the course of the dehydration period which lasted until Thursday evening (1/3 L each night at 2130). The mild exercise consisted of intervals of running (6 mph - 0 grade) on a treadmill or riding a stationary bicycle (50 watts) for a total of 1-2 hours each day. Subjects rehydrated freely Thursday starting at 2000. Control subjects maintained the same schedule without fluid restrictions.

Cold Test. The standard cold test consisted of sitting in a cold chamber ($0^{o}C$) dressed comfortably in standard military cold weather clothing for 135 minutes. After 15 minutes, the mitten, mitten liner and glove liner were removed from the right hand and the bare hand rested on plastic mesh material to allow air circulation. Wind speed at the subjects' exposed hand was less than 0.5 m sec^{-1}.

The temperature of the right hand was measured at 4 sites: thumb, middle finger, little finger and back of hand. Finger temperatures were measured just proximal to the nail bed with exposed copper-constantan thermocouples fastened in place with plastic tape. Skin temperatures were measured at the same 4 sites on the left (gloved and mittened) hand and at 8 additional sites: forehead, right upper arm, left forearm, chest, abdomen, lower back, right medial thigh and right lateral calf. Weighted mean

skin temperatures (MWST) were calculated by the equation of Wenger et al.(18). Rectal temperature (T_r) was also measured by thermocouple. Subjects were removed from the cold chamber whenever any skin temperature reached 4.5°C (safety temperature to preclude cold injury).

All thermocouple voltages were acquired, linearized and referenced to an electronic zero degrees by Numatron scanning system (Leeds and Northrup). The Numatron system was linear when checked with regulated water baths and any temperature value was accurate to $\pm$0.3°C over the range of temperatures used in the study. All temperature data was stored on a computer system (DEC PDP-11/40) and each value was updated once each minute.

The area under the time-temperature curve was used to compare thermal state in order to minimize variation found in other measures (CIVD responses). This measure has been found to be the most reproducible of any index of hand thermal response to cold. Jaeger et. al (19) reported significant variation in time to first CIVD, Amplitude of CIVD, and number of CIVDs when an individual was compared over time. The two measures with high correlation (.94) were the mean temperature and the total area under the curve.

RESULTS

Dehydration. Indirect measures were utilized as indicators of dehydration; loss of body weight was the primary indicator (fig. 1). The dehydration group lost 4.6% of their body weight

over a 2-1/2 day period. Within 10 hours of the initiation of fluid replacement, the dehydration group recovered to a weight deficit of 1.9% (Friday morning). Over the same time course, the controls' weight did not change. The dehydration's group's Friday afternoon weight was only 0.3% lower than their beginning weight (20 hours after rehydration).

Most blood values showed no change from normal values or consistent variation between the dehydration versus control group or across time. However, serum osmolality increased significantly from baseline values for the experimental group on Thursday ($P<.05$) and were significantly different from control group values ($P<.01$) (table 1).

Significant decrease in urine volume of the dehydration group occurred following restriction of fluid intake Monday afternoon (Table 1). Urine volumes for the dehydrated group were significantly lower than the Monday 0630-1830 base line volume ($P<.001$) and also significantly lower than the corresponding control group volume (lowest $P<.05$). Baseline volumes of the two groups were not different.

Changes in specific gravity essentially parallelled the changes in urine volume. Specific gravities were not significantly different between groups for either Monday collection period. Subsequently, values were different for all periods ($P<.001$). The dehydration group specific gravity values for the first three and last (Friday) collection period were not

significantly different; the remaining values were different from these four periods ($P<.05$).

Urine sodium and chloride values were not different between groups. Urine potassium values were significantly higher for the hypothermic group for all collection periods except the first and last ($P<.01$).

Whole Body Cooling. To determine whether the whole body thermal state of the subjects differed from day to day, the mean values for T_r and MWST were calculated for the 135 minute cold test. There were no differences between groups or across the 3 periods of cold testing.

Peripheral Responses to Cooling. The areas under the temperature-time curve for the control subjects were the same for all periods of standard cold tests (Fig. 2).

The preliminary and Monday standard cold test values for the dehydration group were virtually identical. Subsequently, the area under the curve dropped on Thursday (following dehydration) and partially returned toward the Monday values on Friday. The area under the cooling curve for eight of the 10 dehydrated subjects was higher on Friday than Thursday, while lower Friday values for the other 2 subjects may have masked any reduced cooling following rehydration.

Inspection of figure 2 indicates that the baseline values of the control and dehydration group are not homogeneous, but the difference was not significant. Any group differences would be of

little importance since each subject serves as his own control. To eliminate the differences in baseline values for the groups, the data were calculated as the difference for each subject from his baseline (Monday) value for Thursday and Friday (Figure 3).

There were no differences either across time or between groups, for the right back of hand area. In contrast, the area under the cooling curve was less for the dehydration group on both Thursday and Friday than that for the control group ($P<.001$). For the dehydration group, this decreased area on Thursday was significantly different from pre-dehydration values ($P<.001$). The area for the right thumb remained low on Friday (Rehydration) and was significantly different from Monday. In contrast, the area for the middle and little finger had increased sufficiently on Friday (Rehydration) so that it was not significantly different from either pre-dehydration or dehydration values. In all cases, the control group declines were not significantly different from each other or from zero (baseline).

DISCUSSION

This study was designed to examine the relationship of hypohydration and peripheral cooling. Other factors which might have affected this response were minimized by having each subject serve as his own control.

The evidence of hypohydration is very strong even without direct measures of total body water, plasma volume, and extracellular fluid volume. The rapid recovery of weight loss

indicated that it was more likely due to loss of water, not body tissue. Hemoconcentration (increased serum osmolality) and urine concentration and decreased volume are the physiological changes one would expect to find in dehydrated subjects. Thus, the changes in blood and urine parameters, coupled with the maintenance of caloric intake strongly supports the development of dehydration by the experimental subjects. Plasma volume was calculated according to the predictive equation of Dill and Costill (20); however, the results were not conclusive. For the dehydration subjects a change from baseline of 2.3 $\pm$ 1.8% occurred. This change was not significantly different from zero, that is, no change of plasma volume. One might have predicted a decrease in calculated plasma volume and an increase in hematocrit for dehydrated subjects, but this did not occur. The explanation for this lack of change involves the use of exercise during the dehydration phase. During exercise, it has been noted that protein enters the vascular volume and exerts an increased osmotic pressure which protects the vascular volume. Large decreases in plasma volume have been found in a number of studies as a result of acute dehydration from heat exposure with and without exercise (20). These acute decreases probably do not reflect true changes of hypohydration. However, a decline of 4.4% for calculated plasma volume was found in a similar study (2). In that study, high school wrestlers exercised and restricted fluid intake for two days, but also starved themselves.

The whole body cooling which occurred during the standard cold tests were slight, and, at any rate, the same for both groups and the same for all standard cold tests.

Nonetheless, the dehydrated subjects' hands were significantly colder following fluid loss. The area under the temperature-time curve (that is, average temperature) was 18% lower than their baseline value. The cooler finger temperatures almost certainly represent decreased finger blood flow, since finger blood flow is approximately 90% skin blood flow and there is little metabolizing tissue (18).

The mechanism of this increased cooling rate following hypohydraton is not clear. There was no apparent decrease in circulating fluid volumes, so if this were the mechanism, then it would require pooling of blood in the core or decreasing peripheral flow to conserve body heat. This could be a neurogenic reflex triggered by fluid loss or it could be an increased rate of heat loss from tissue with a reduced specific heat due to water loss. Obviously this study did not address mechanisms of reduced peripheral blood flow. Rather, our question was simply to identify whether or not increased peripheral cooling occurred in the presence of dehydration.

The data presented indicates that denydration can result in a colder hand and as such may lead to increased incidence of cold injury. It is recommended that persons exposed to field conditions where dehydration can occur be very careful to maintain hydration to avoid increased risk of cold injuries.

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Human subjects participated in these studies after giving their free and informed voluntary consent. Investigators adhered to AR 70-25 and USAMRDC Regulation 70-25 in Use of Volunteers in Research.

TABLE LEGEND

Table 1 -- Physiological Variables Indicative of Dehydration.

FIGURE LEGENDS

Figure 1 -- Mean body weight loss for both groups.

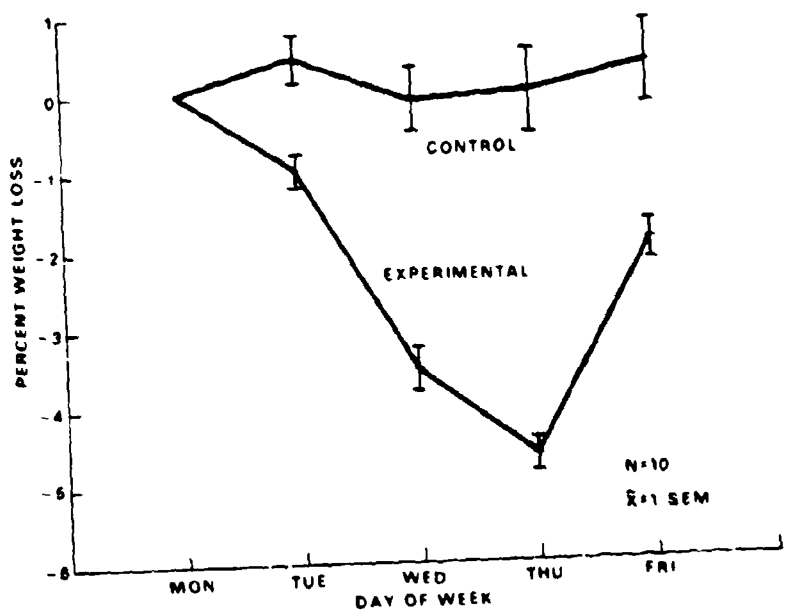
Figure 2 -- Mean areas under the temperature curves for the 120 min cold exposures.

Figure 3 -- The change in Area for temperature-time curves from Monday baseline values.

	URINE VOLUME ml/hr		URINARY SPECIFIC GRAVITY		SERUM OSMOLALITY	
	CONTROL	DEHYDR.	CONTROL	DEHYDR.	CONTROL	DEHYDR.
MON.	68 ± 7	63 ± 5	1.0225 ± 0.0015	1.0238 ± 0.0008	288 ± 1	290 ± 2
TUES.	49 ± 7	32 ± 2 *	1.0227 ± 0.0022	1.0273 * ± 0.0007	293 ± 3	292 ± 2
THURS.	63 ± 11	31 ± 3 *	1.0178 ± 0.0015	1.0308 * ± 0.0008	294 ± 3	302 ± 1 *
FRI.	52 ± 6	34 ± 4 *	1.0210 ± 0.0015	1.0314 * 0.0009	292 ± 2	294 ± 1

* $P < 0.001$ $\bar{X} \pm SEM$

table 1



1
0
-1
-2
-3
-4
-5
-6
PERCENT WEIGHT LOSS
CONTROL
EXPERIMENTAL
N=10
X̄±1 SEM
MON
TUE
WED
THU
FRI
DAY OF WEEK

Figure 1.

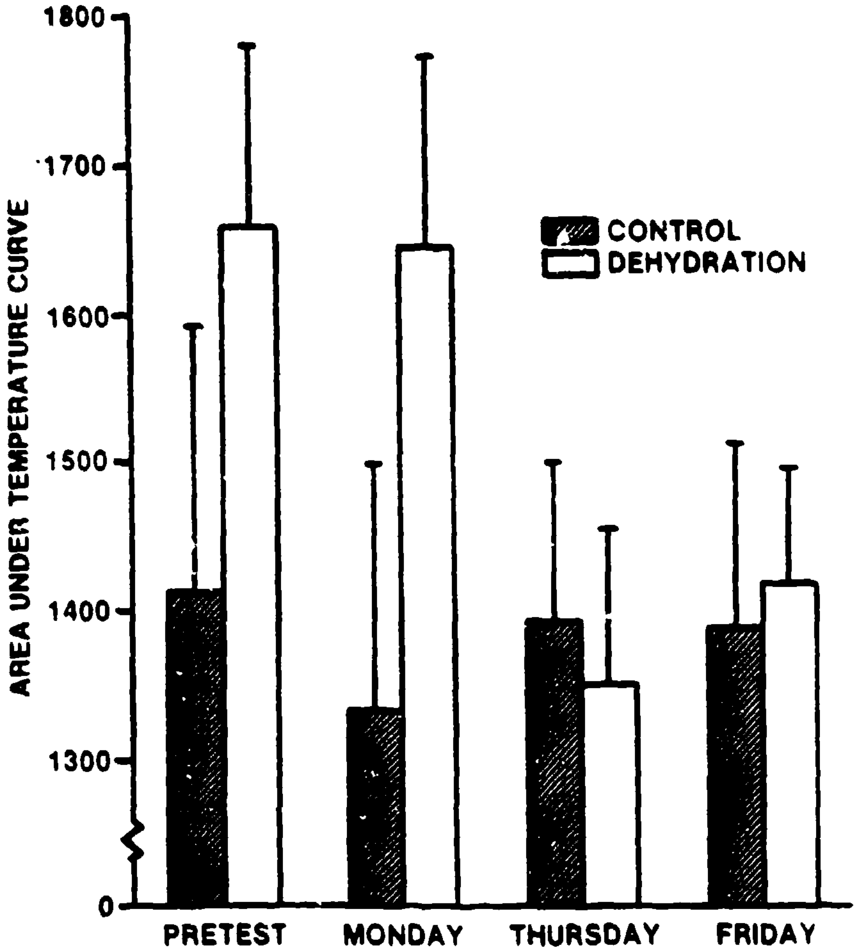
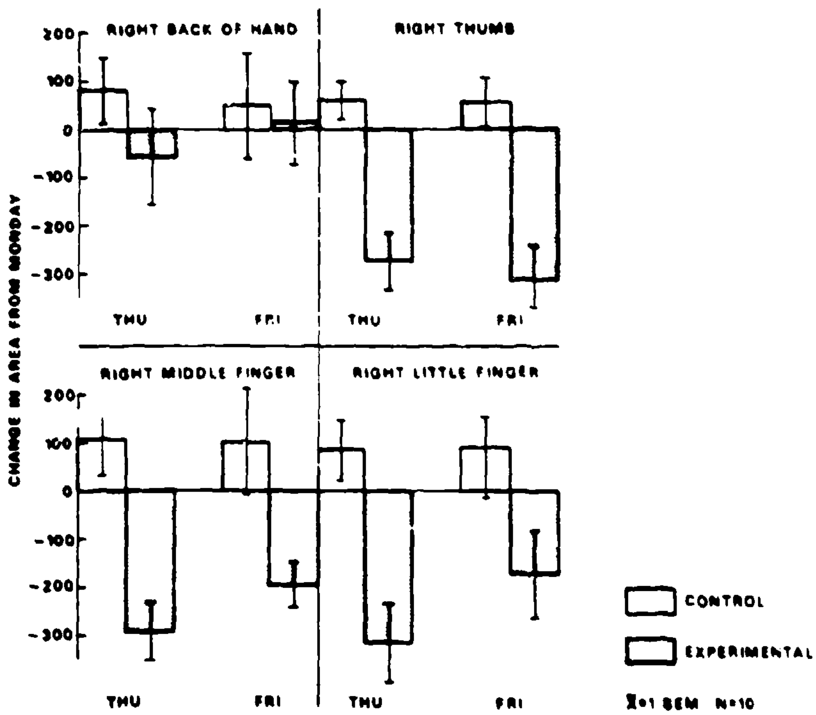

1800
1700
1600
1500
1400
1300
0
AREA UNDER TEMPERATURE CURVE
CONTROL
DEHYDRATION
PRETEST
MONDAY
THURSDAY
FRIDAY

Figure 2



RIGHT BACK OF HAND
RIGHT THUMB
RIGHT MIDDLE FINGER
RIGHT LITTLE FINGER
CHANGE IN AREA FROM MONDAY
200
100
0
-100
-200
-300
THU
FRI
THU
FRI
CONTROL
EXPERIMENTAL
X̄±1 SEM N=10

Figure 3